NASA TECHNICAL MEMORANDUM

NASA TM X-52552

NASA TM X-52552

EFFECT OF AXIAL RUNNING CLEARANCE ON PERFORMANCE OF TWO BRAYTON CYCLE RADIAL INFLOW TURBINES

by Samuel M. Futral and William J. Nusbaum
Lewis Research Center
Cleveland, Ohio

February, 1969

NASA TM X-52552

EFFECT OF AXIAL RUNNING CLEARANCE ON PERFORMANCE OF TWO BRAYTON CYCLE RADIAL INFLOW TURBINES

by Samuel M. Futral and William J. Nusbaum

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

EFFECT OF AXIAL RUNNING CLEARANCE ON PERFORMANCE OF TWO BRAYTON CYCLE RADIAL INFLOW TURBINES

by Samuel M. Futral and William J. Nusbaum

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

ABSTRACT

The effect of increasing the axial running clearance on the efficiency and mass flow rate was determined experimentally. The variation in clearance was accomplished by appropriate shimming of the scroll. The two radial inflow turbines involved had 5-inch 12.62-cm) and 6-inch (15.29-cm) rotor tip diameters. The results indicated little effect on efficiency with a 1 percent increase in clearance-to-height ratio yielding a 1/5 to 1/3 percent change in efficiency. The associated effect on mass flow rate was found to be slight.

E-4934

EFFECT OF AXIAL RUNNING CLEARANCE ON PERFORMANCE OF TWO BRAYTON CYCLE RADIAL INFLOW TURBINES

by Samuel M. Futral and William J. Nusbaum

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

SUMMARY

Two radial-inflow turbines, one of 6-inch (15.29-cm) and one of 5-inch (12.62-cm) rotor tip diameter, were investigated to determine the effects of increased axial clearance on aerodynamic performance. Clearance increases were accomplished by inserting shims between the rotor bearing housing and the scroll. Maximum clearance covered was 25 percent of the passage height. Results are presented in the form of the ratio of total efficiency decrease to the design point value of total efficiency, expressed in percent. Corresponding results for mass flow rate were obtained by dividing the decrease in flow rate by the design point rate and expressing this as a percentage.

For the 6-inch (15.29-cm) turbine, the total efficiency decreased about 1/5 percent for each percent increase in clearance for clearance values to about 11 percent. The corresponding result for the 5-inch (12.62-cm) turbine was about 1/3 percent decrease in total efficiency for each percent increase in clearance. The loss in mass flow rate was about the same for both turbines for clearances up to about 11 percent. Calculated as described above, the mass flow rate decrease was about 0.2 percent for each percent increase in clearance.

From these results it was concluded that radial inflow turbine efficiency is not greatly affected by increases in axial running clearance by relocating the scroll assembly. The associated effect on weight flow is only slight. Therefore, rather generous axial clearances can be employed

TM X-52552

in these turbines, particularly during a hot package development program, without serious aerodynamic consequences.

INTRODUCTION

The NASA Lewis Research Center has been investigating the turbine components of Brayton space power systems designed in the 2 to 10 kilowatts power output range. One of the facets of this program has been the study of rotor tip clearances as effecting turbine performance. Component aerodynamic studies are usually made with cold working fluids such as argon or air and therefore can employ close clearances. However, it is important to determine the extent of the performance penalties as these clearances are increased for hot running of the turbine as part of a complete Brayton package.

This report is therefore concerned with the effect on performance of increasing the rotor inlet tip clearance for two radial inflow turbines involved in the Brayton program. Variations in this clearance were obtained by repositioning the turbine scroll axially such that radial tip clearance at the rotor exit remained constant. The first turbine, having a 5-inch (12.62-cm) rotor tip diameter and designed as part of a single shaft Brayton cycle power system, was tested at three different values of axial tip clearance. The general performance of this turbine at design clearance is reported in reference 1. The other turbine, of 6-inch (15.29-cm) tip diameter, designed for a 2-shaft Brayton cycle power system, was tested at four values of axial clearance. Reference 2 is the general performance report for this turbine at design clearance.

This report includes a description of these two turbines, the manner in which the axial clearance was varied, and the results of the aerodynamic study. The effect of clearance on both efficiency and mass flow rate will be considered.

SYMBOLS

H	isentropic specific work (based on total pressure ratio), ft-lb/lb (J/g)
N	turbine rotative speed, rpm
N_s	specific speed, $NQ^{1/2}/H^{3/4}$, rpm(ft)$^{3/4}$/sec$^{1/2}$; (rad)(m)$^{3/2}$ (kg)$^{3/4}$/(sec)$^{3/2}$(J)$^{3/4}$
p	pressure, psia (N/cm^2)
Q	volume flow (based on exit conditions), ft^3/sec (m^3/sec)
T	absolute temperature, $^{\circ}$R (K)
U_t	rotor tip speed, ft/sec (m/sec)
V	absolute gas velocity, ft/sec (m/sec)
V_j	ideal jet speed corresponding to total-to-static pressure ratio across turbine, ft/sec (m/sec)
w	mass flow rate, lb/sec (kg/sec)
γ	ratio of specific heats
δ	ratio of inlet total pressure, to U. S. standard sea level pressure, p_0'/p^*
ϵ	function of γ used in relating parameters to those using air inlet conditions at U. S. standard sea-level conditions, $\frac{0.740}{\gamma}\left(\frac{\gamma+1}{2}\right)^{\gamma/\gamma-1}$
η	turbine total efficiency
θ_{cr}	squared ratio of critical velocity at turbine inlet to critical velocity at U. S. standard sea level temperature, $(V_{cr}/V_{cr}^*)^2$
ν	blade-jet speed ratio (based on rotor inlet tip speed), U_t/V_j

Subscripts:

cr condition corresponding to Mach number of unity

eq equivalent

0 station at turbine inlet

2 station at rotor exit

Superscripts:

' absolute total state

* U. S. standard sea level conditions (temperature equal to 518.67° R (288.15 K) and pressure equal to 14.70 psia (10.13 N/cm^2)

DESCRIPTION OF THE TURBINES

The two turbines used in this investigation were used in the Brayton cycle component investigation program and are described fully in references 1 and 2. Briefly, they were radial-inflow turbines with rotor tip diameters of 6 and 5 inches (15.29 and 12.62 cm). The 6-inch (15.29-cm) unit was designed to drive the compressor in a two-shaft system, whereas, the smaller turbine was designed specifically for a single-shaft system. A summary of the characteristics of the two turbines is presented in table I. Although the requirements are generally about the same for the two turbines, there is a significant difference in the values of specific work and of specific speed. A specific work value of 34.7 Btu per pound (80.77 J/g) is required of the 6-inch (15.29-cm) turbine as compared to 21.8 Btu per pound (50.75 J/g) for the smaller turbine. A specific speed value of 76.0 for the 5-inch (12.7-cm) turbine falls within the optimum range of 75 to 85. The value of 95.6 for the 6-inch (15.24-cm) turbine is somewhat greater than the optimum. The design requirements thus indicate a better performance by the smaller turbine, and this has been experimentally verified. Photographs of the two turbines are shown in figures 1 and 2.

APPARATUS AND PROCEDURE

Apparatus

Descriptions of the apparatus and instrumentation used have been given in references 1 and 2, and will not be given here. A schematic of the experimental equipment is shown in figure 3. This is typical for tests of this type at Lewis Research Center.

Procedure

Variations in the axial clearance between rotor and scroll were obtained by inserting shims between the flanges connecting the scroll to the bearing housing. Figure 4 is a cross-sectional drawing of the 6-inch (15.29-cm) turbine. Location of the shims is indicated on the drawing. The construction of the 5-inch (12.62-cm) turbine is similar.

The 5-inch (12.62-cm) turbine was tested at clearances of 2.53, 4.94, and 10.47 percent of the passage height. Tests of this turbine, at each clearance value, were conducted at constant design equivalent speed. The equivalent total-to-static pressure ratio was varied from 1.45 to 1.9 at each clearance.

The 6-inch (15.29-cm) turbine was tested at clearance values of 1.7, 1.94, 8.1, and 25 percent of the passage height. Tests on this turbine were conducted at a constant value of 1.54 for the equivalent total-to-static pressure ratio. Speed was varied from 30 to 110 percent of the design equivalent value.

EXPERIMENTAL RESULTS

The extent to which axial clearance variations affect total efficiency is shown in figures 5(a) and (b). The difference between the general shapes

of the two sets of curves is due to the fact that constant pressure ratio tests were used for the 6-inch (15.29-cm) turbine while constant speed tests were used for the 5-inch (12.62-cm) turbine. This applies also to the curves of equivalent mass flow rate of figures 6(a) and (b). Examination of the curves of figures 5 and 6 shows that increases in axial clearance does not significantly alter the shape of the curves for either efficiency or mass flow rate. Increased clearance resulted in a small decrease in both efficiency and mass flow rate at every running condition.

The loss in total efficiency, for both turbines is shown in figure 7. The values were obtained by dividing the reduction in efficiency from the value at design axial clearance by the design point efficiency and then expressing the result as a percentage. This is plotted against the axial clearance, expressed as a percentage of the passage height. A similar plot, for loss in equivalent mass flow rate, is shown in figure 8. Data points for figures 7 and 8 include only points at design equivalent conditions.

For clearances up to about 12 percent of passage height, the rate of efficiency loss was slightly greater for the 5-inch (12.62-cm) turbine than for the 6-inch (15.29-cm) turbine. Figure 7 shows that the efficiency decreased only about 1/3 percent for each percent increase in clearance for the 5-inch (12.62-cm) turbine. For the 6-inch (15.29-cm) turbine this was about 1/5 percent for each percent increase in clearance. Figures 5(a) and (b), however, show that the efficiency at design point operation was higher for the 5-inch (12.62-cm) turbine at all values of clearance.

From figure 8, the loss in mass flow rate for both turbines is seen to increase only about 0.2 percent for each percent increase in clearance over the 11 percent clearance range.

CONCLUDING REMARKS

The results of this investigation have shown that radial inflow turbine efficiency is not greatly affected by increases in axial running clearance by relocating the scroll assembly. The associated effect on weight flow is

only slight. Therefore, rather generous axial clearances can be employed in these turbines, particularly during a hot package development program, without serious aerodynamic consequences.

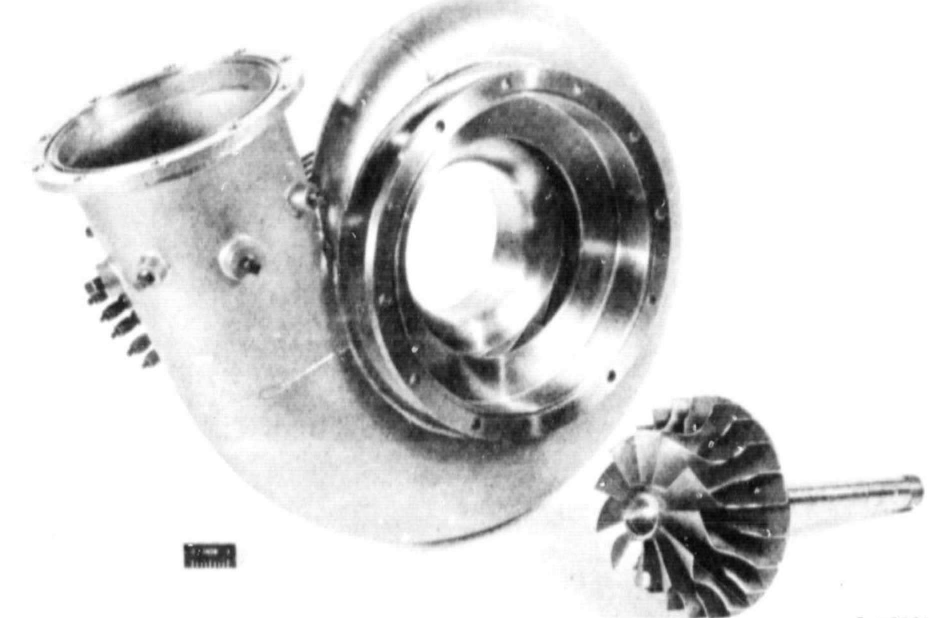
REFERENCES

1. Nusbaum, William J.; and Kofskey, Milton G.: Cold Performance Evaluation of 4.97-Inch Radial-Inflow Turbine Designed for Single-Shaft Brayton Cycle Space-Power System. NASA TN D-5090, 1969.

2. Kofskey, Milton G.; and Holeski, Donald E.: Cold Performance Evaluation of a 6.02-Inch Radial Inflow Turbine Designed for a 10-Kilowatt Shaft Output Brayton Cycle Space Power Generation System. NASA TN D-2987, 1965.

TABLE I. - CHARACTERISTICS OF TEST TURBINES

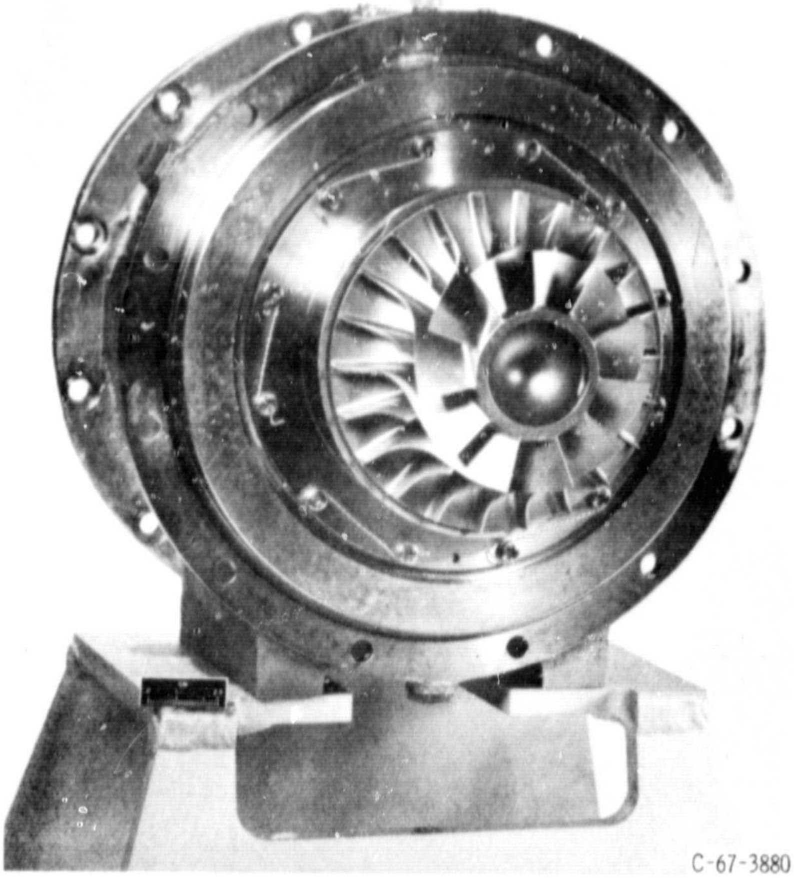
Characteristic	6-inch Turbine	5-inch Turbine
Design working fluid	Argon	Helium-xenon mol. wt. of 83.7
Design inlet total temperature, T_0', $^{\circ}R$ (K)	1950 (1083)	2060 (1144)
Design inlet total pressure, p_0', psia (N/cm^2)	13.20 (9.10)	25.00 (17.24)
Design pressure ratio, total-static, p_0'/p_2	1.613	1.800
Design rotative speed, rpm	38 500	36 000
Design mass flow rate, lb/sec (kg/sec)	0.611 (0.277)	0.7484 (0.3395)
Design specific speed, N_s	95.6 (0.741)	76 (0.589)
Design blade-jet speed ratio, ν	0.697	0.690
Rotor tip diameter, in. (cm)	6.02 (15.29)	4.97 (12.62)
Number of stator vanes	14	13
Number of rotor blades	11 Blades and 11 splitters	11 Blades and 11 splitters
Working fluid for tests	Air	Argon
Design equivalent total-static pressure ratio, p_0'/p_2	1.54	1.695
Equivalent mass flow rate, at eq. design conditions, lb/sec (kg/sec)	1.068 (0.484)	0.486 (0.220)
Total efficiency at equivalent design conditions, η	0.887	0.897



C-72323

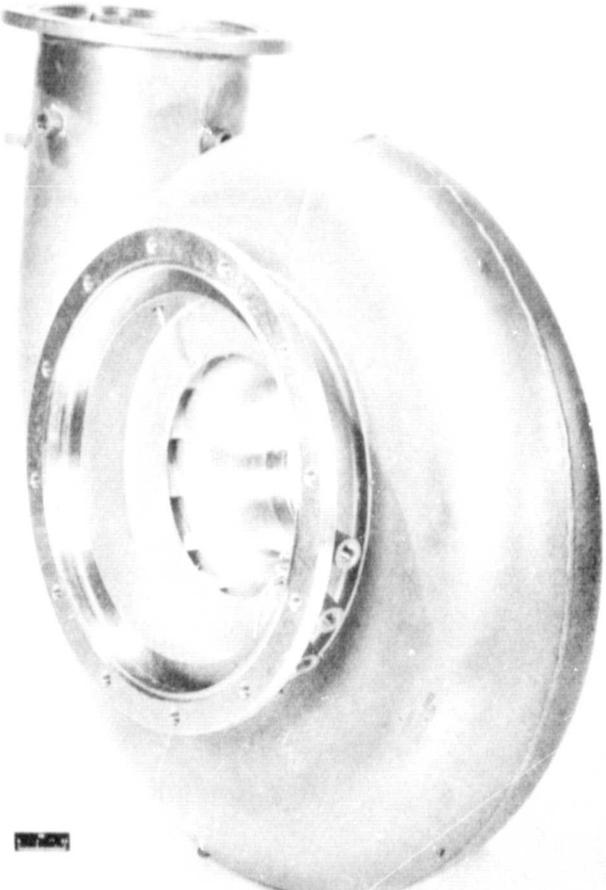
Figure 1. - Turbine rotor and scroll-stator assembly.

E-4934



C-67-3880

(a) Rotor and bearing housing assembly.



C-67-3883

(b) Scroll-stator assembly.

Figure 2. - Assemblies for 5-inch turbine.

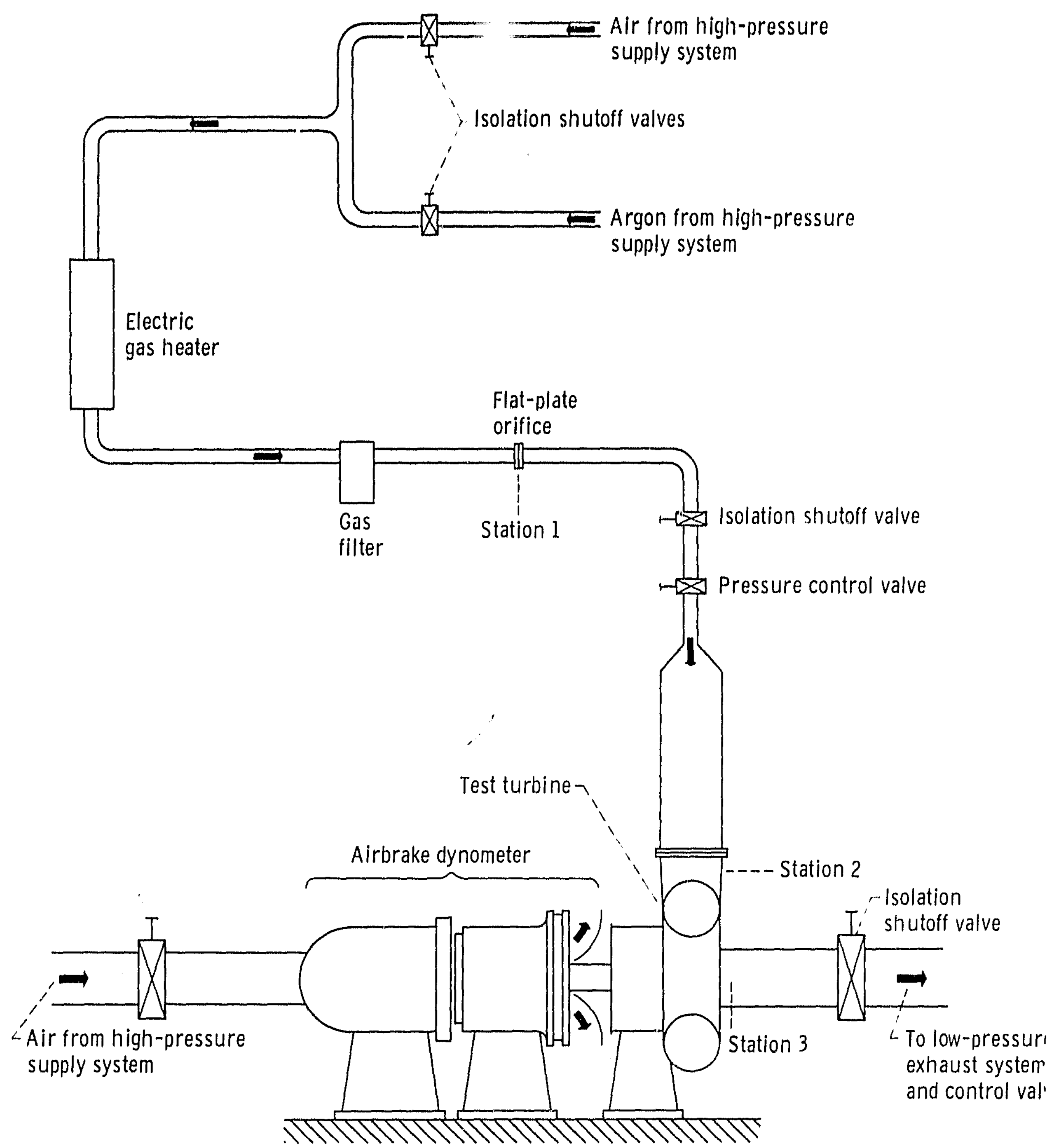


Figure 3. - Experimental equipment.

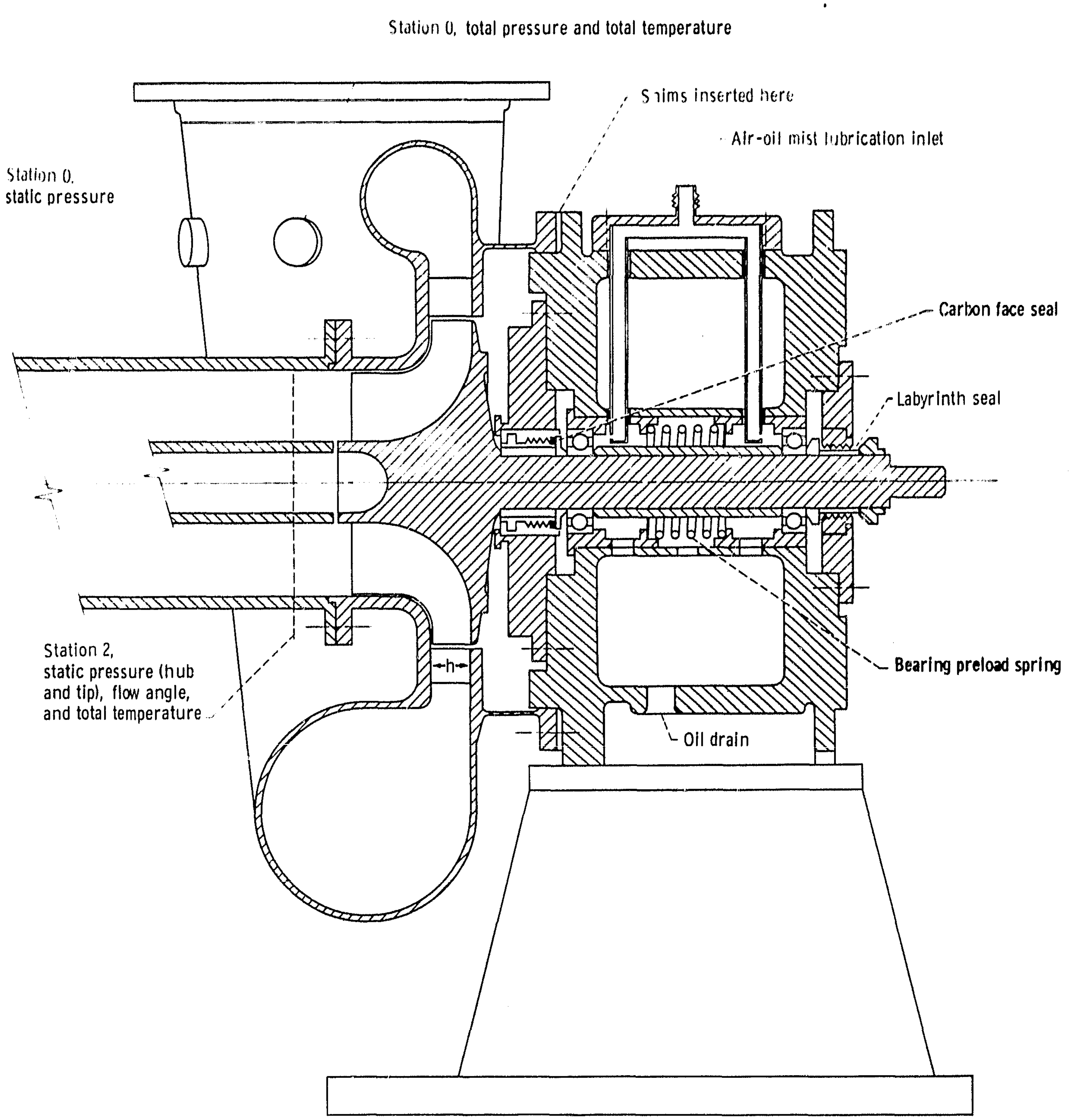


Figure 4. - Cross section of turbine and bearing housing.

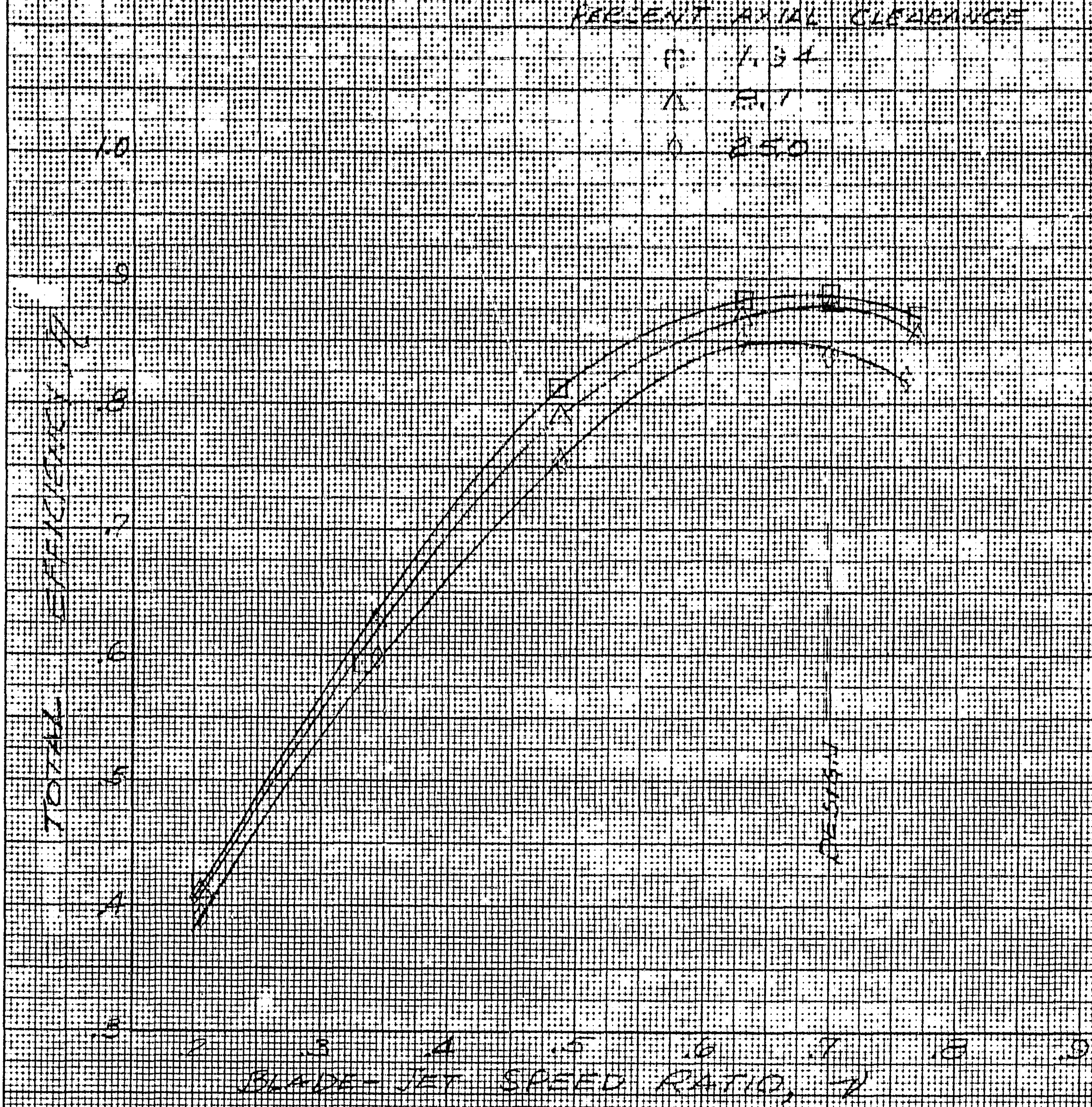


FIGURE 5(a) VARIATION OF TOTAL EFFICIENCY WITH BLADE-JET SPEED RATIO FOR VALUES OF AXIAL CLEARANCE.

6-INCH TURBINE TESTED AT CONSTANT INLET TOTAL- AND EXIT STATIC PRESSURES.

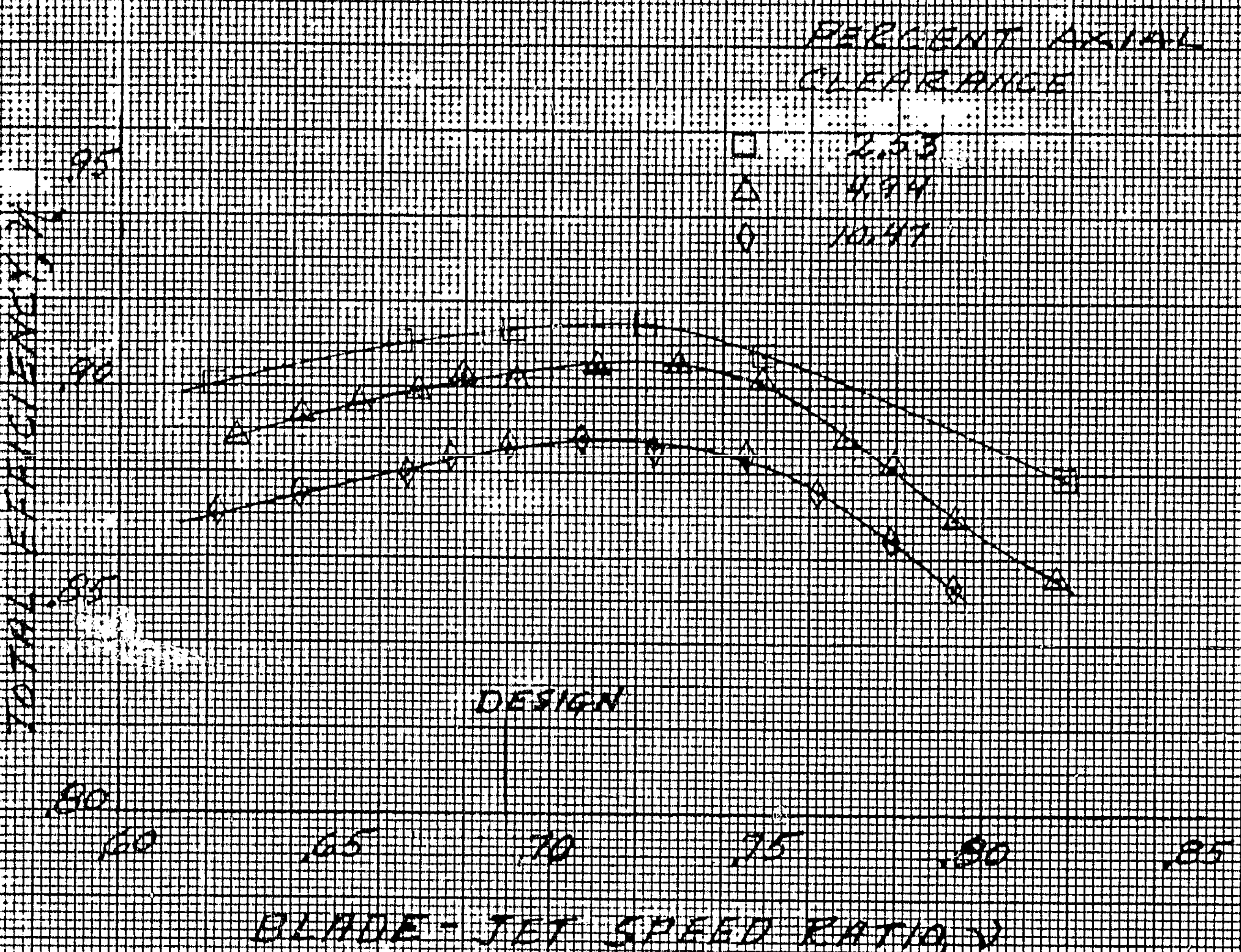


FIGURE 5(b) VARIATION IN TOTAL EFFICIENCY WITH BLADE-JET SPEED RATIO FOR VALUES OF AXIAL CLEARANCE.
5-INCH TURBINE TESTED AT CONSTANT SPEED WITH VARYING PRESSURE RATIO

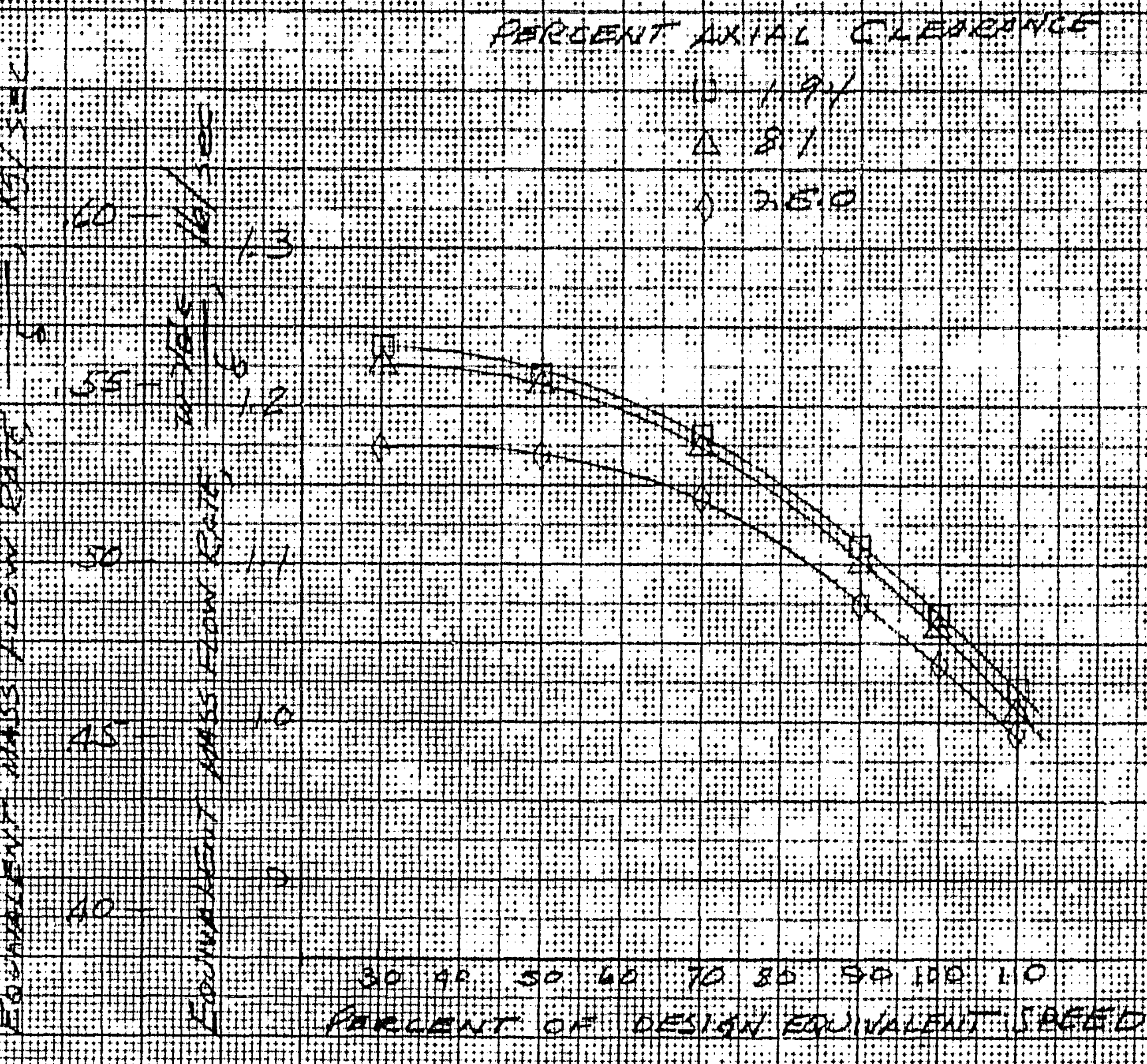


FIGURE 6(B) VARIATION OF MASS FLOW RATE WITH EQUIVALENT SPEED, FOR VALUES OF AXIAL CLEARANCE

6-INCH TURBINE TESTED AT CONSTANT VALUES OF INLET TOTAL PRESSURE AND EXIT STATIC PRESSURE

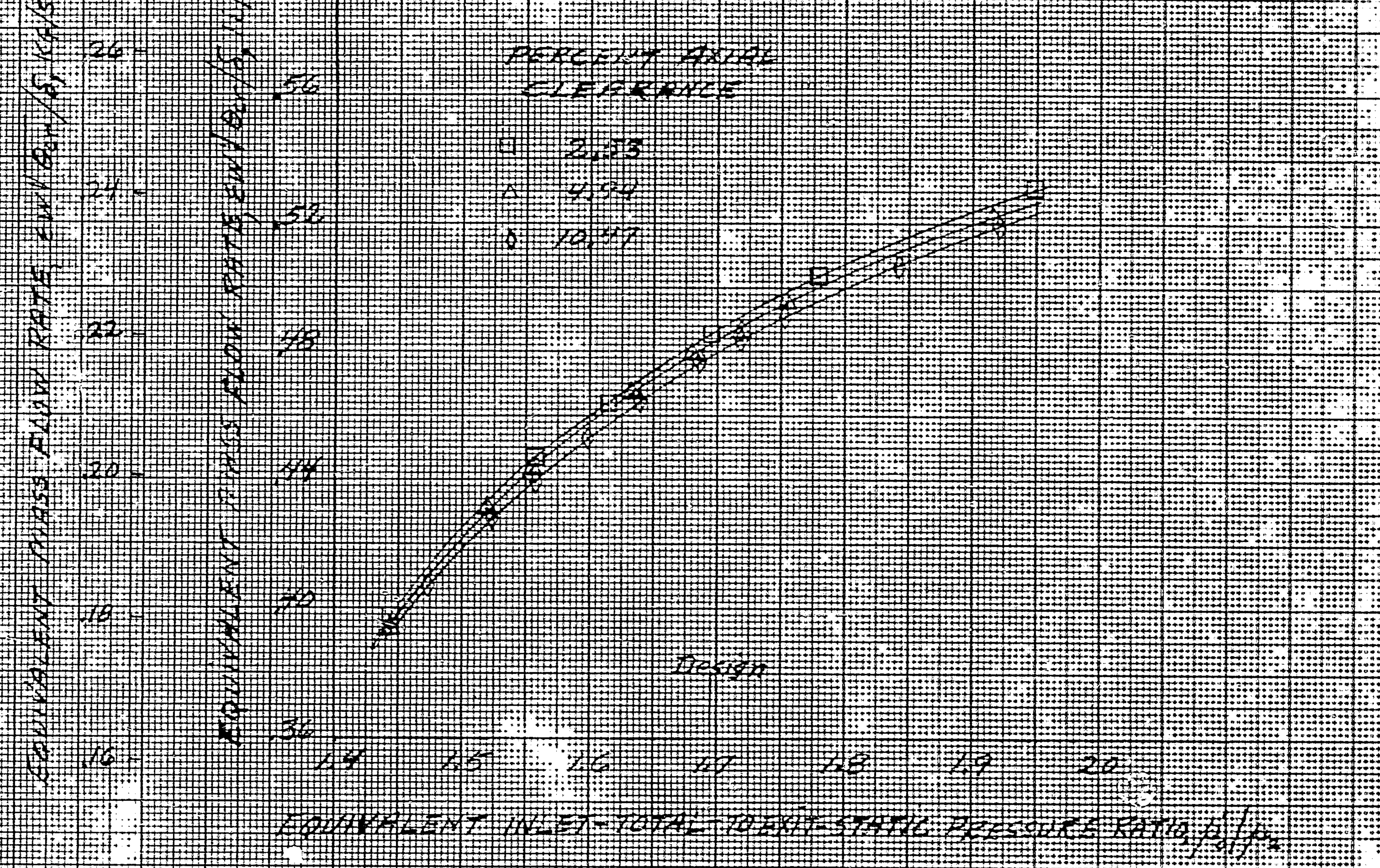


FIGURE 6(A) - VARIATION OF MASS FLOW RATE WITH PRESSURE RATIO FOR VALUES OF AXIAL CLEARANCE.

5-INCH TURBINE TESTED AT CONSTANT SPEED WITH VARYING PRESSURE RATIO

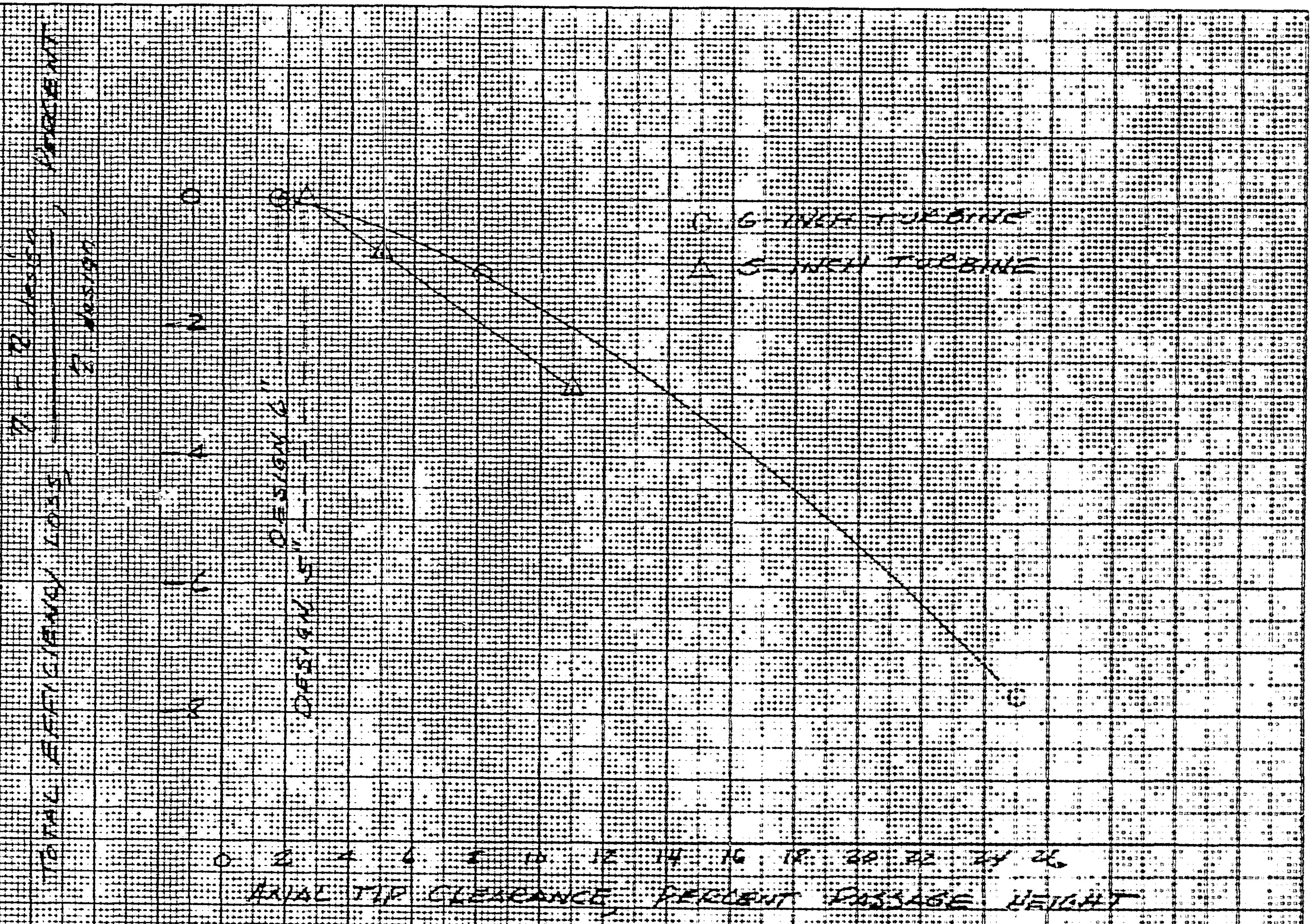


FIGURE 7 EFFECT OF AXIAL TIP CLEARANCE ON TOTAL EFFICIENCY AT EQUIVALENT DESIGN CONDITIONS

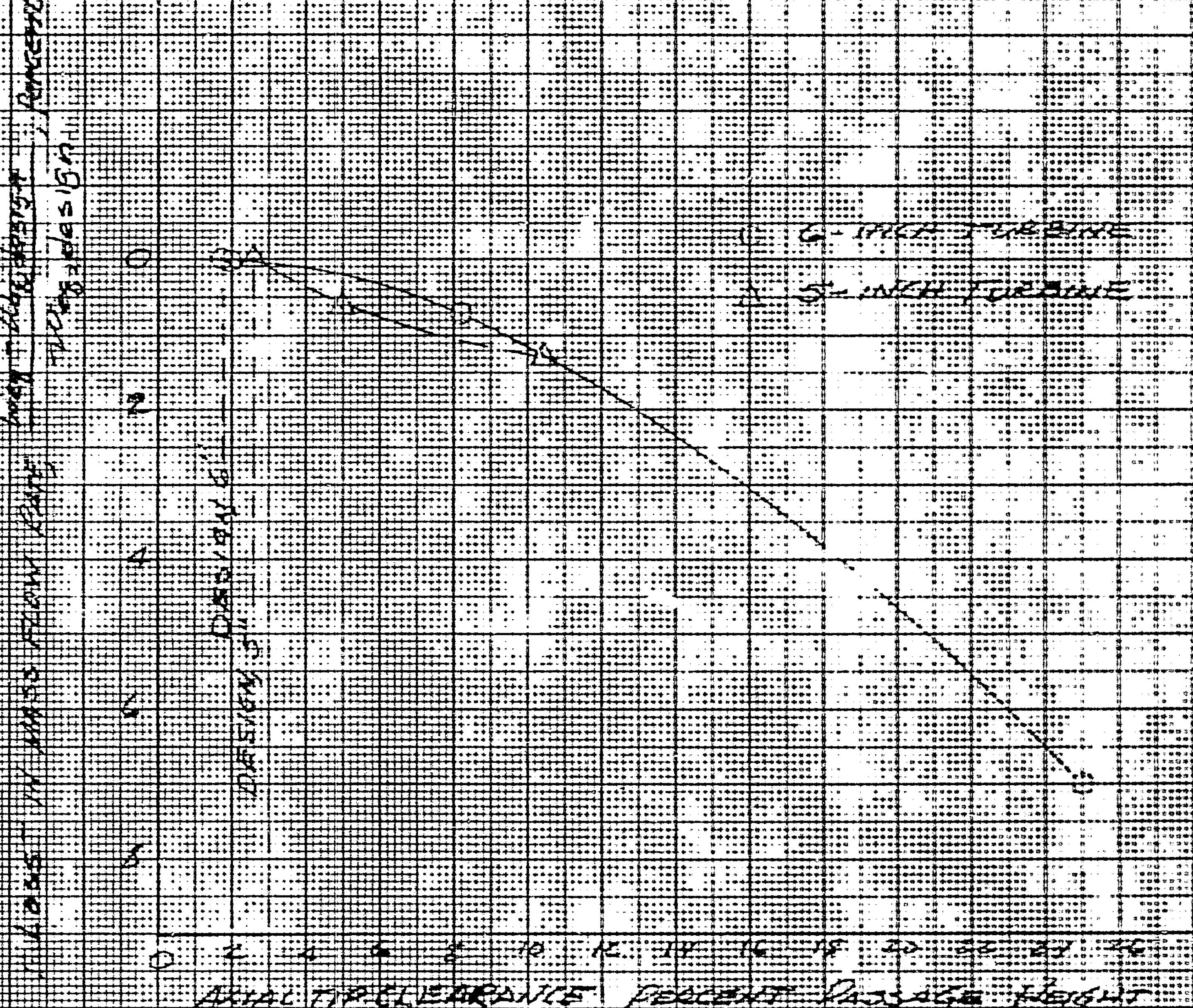


FIGURE 8 EFFECT OF AXIAL TIP CLEARANCE ON MASS FLOW RATE AT EQUIVALENT DESIGN CONDITIONS